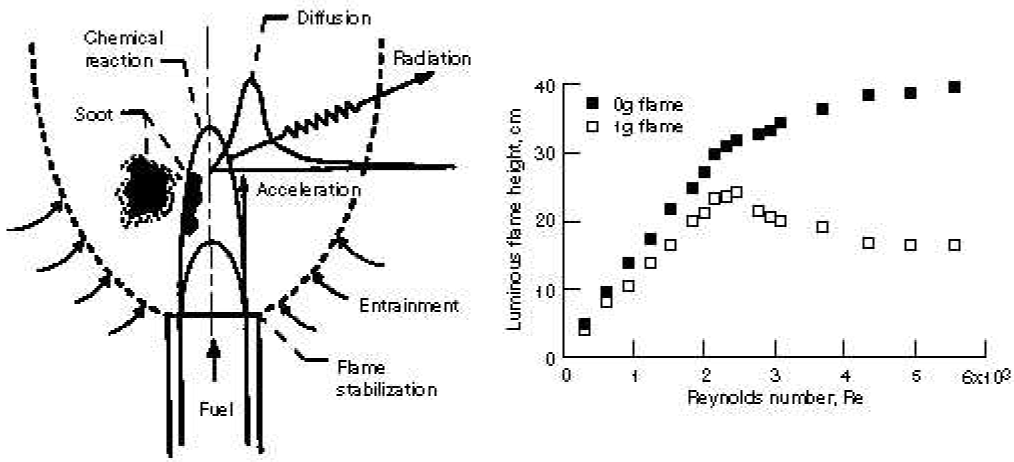
Microgravity Turbulent Gas-Jet Diffusion Flames

A gas-jet diffusion flame is similar to the flame on a Bunsen burner, where a gaseous fuel (e.g., propane) flows from a nozzle into an oxygen-containing atmosphere (e.g., air). The difference is that a Bunsen burner allows for (partial) premixing of the fuel and the air, whereas a diffusion flame is not premixed and gets its oxygen (principally) by diffusion from the atmosphere around the flame. Simple gas-jet diffusion flames are often used for combustion studies because they embody the mechanisms operating in accidental fires and in practical combustion systems (see the sketch on the left side of the figure).



Left: Schematic of the structure of a gas-jet diffusion flame. Right: Measured flame height as a function of injection Reynolds number for propane-air flames in microgravity and normal gravity.

However, most practical combustion is turbulent (i.e., with random flow vortices), which enhances the fuel/air mixing. These turbulent flames are not well understood because their random and transient nature complicates analysis. Normal gravity studies of turbulence in gas-jet diffusion flames can be impeded by buoyancy-induced instabilities. These gravity-caused instabilities, which are evident in the flickering of a candle flame in normal gravity, interfere with the study of turbulent gas-jet diffusion flames. By conducting experiments in microgravity, where buoyant instabilities are avoided, we at the NASA Lewis Research Center hope to improve our understanding of turbulent combustion. Ultimately, this could lead to improvements in combustor design, yielding higher efficiency and lower pollutant emissions.

Gas-jet diffusion flames are often researched as model flames, because they embody mechanisms operating in both accidental fires and practical combustion systems (see the first figure). In normal gravity laboratory research, buoyant air flows, which are often negligible in practical situations, dominate the heat and mass transfer processes. Microgravity research studies, however, are not constrained by buoyant air flows, and new, unique information on the behavior of gas-jet diffusion flames has been obtained.

The graph shows the observed flame height as a function of the fuel-injection Reynolds number (which is related to the fuel flow rate for a given injection nozzle size) for flames in both normal gravity and microgravity. Below a Reynolds number of approximately 2000, both flames exhibit laminar characteristics, and the flame height increases with an increase in the Reynolds number. Because of the lack of buoyant convection, which enhances combustion in normal gravity, the microgravity flames are larger.

In the Reynolds number range of 2000 to 3000, the flames undergo a transition process from laminar to turbulent burning. In normal gravity, this process is characterized by a decrease in the flame height and the appearance of instabilities (flame disturbances) that first appear near the flame tip but begin to originate at lower locations with increases in Reynolds number. In microgravity, the flame height continues to increase, although at a lower rate than in the laminar regime. In contrast to the normal gravity case, flame disturbances in microgravity are first observed near the base of the flame instead of near the tip. Flame instabilities arise primarily at locations of large velocity gradients. In normal gravity, because of buoyant acceleration, velocity gradients are maximum near the flame tip so instabilities are first observed there. In microgravity, velocity gradients are maximum near the base of the flame, and that is where disturbances are first observed.

Beyond a Reynolds number of approximately 3000, turbulent conditions prevail. In normal gravity, in the turbulent regime, the flame height remains constant with the Reynolds number until close to flame blowoff. This feature is explained in terms of a balance between turbulent transport processes and jet momentum. However, in microgravity, the flame height continues to increase with Reynolds number, indicating that jet momentum dominates turbulent transport in this case.

The normal gravity behavior shown in the second figure is similar to that appearing in virtually all combustion science textbooks. It was anticipated that buoyant effects in the turbulent regime would be small and that the behavior of microgravity and normal gravity flames would be identical. This is obviously not the case. We anticipate that microgravity data, which give better insights into the controlling mechanisms for gas-jet diffusion flames, will find its way into textbooks of the future.